Saskatchewan
Agriculture
and Food

ADF

AGRICULTURE DEVELOPMENT FUND

FINAL REPORT

19990089

DEVELOPMENT OF IMIDAZOLINONE (IMI) TOLERANT LENTIL

Funded by: The Agriculture Development Fund

February 2004

Prepared by: University of Saskatchewan

Final Project Report

ADF Project Number 99000089 Res 79 BW

Development
of an
Imidazolinone (IMI) Tolerant Lentil

Dr. B. Vandenberg
&
F.A. (Rick) Holm, PAg.

Crop Development Centre

University of Saskatchewan

March 2003

1 Abstract

Imidazolinone tolerant lentil breeding lines were developed as part of this project. Genetic analysis showed that the imidazolinone tolerance trait is conferred by a single dominant gene. Research on the effects of imazamox and imazethapyr herbicides on tolerant lentil genotypes showed that high rates of herbicide can be used over a wide range of growth stages without affecting flowering date, maturity or yield. The tolerant genotypes are susceptible to damage from other Group 2 herbicides.

2 Executive Summary

A series of experiments was conducted during this project to determine the inheritance and the agronomic and breeding potential of the lentil line RH44 which shows imidazolinone tolerance. The genetic study indicated clearly that RH44 confers tolerance to imidazolinone herbicides through the action of a single dominant gene. This gene can be used in lentil breeding applications to develop new lentil varieties with tolerance to imidazolinone herbicides through back-crossing. Analysis of breeding populations in diverse genetic backgrounds including the small red, small green, medium green and large green market classes showed that the tolerance gene has no negative effects on yield or other agronomic characteristics.

Greenhouse and field studies were conducted to determine appropriate imidazolinone herbicide application rates, cross tolerances, and stage of application for RH44 lentil in comparison to both unsprayed controls and to genotypes that are susceptible to imidazolinone herbicide injury. Results clearly showed that imidazolinone herbicides such as Pursuit and Odyssey are effective at a wide range of rates and growth stages without injuring RH44 lentil. RH44 does not have tolerance to Express, Refine or Everest. All other current lentil varieties evaluated during this project are injured by imidazolinone herbicide application and often show obvious symptoms of delayed flowering, stunted growth and reduced yield.

In future, it should be possible to develop a new herbicide option for lentil production in Saskatchewan by combining the use of imidazolinone herbicides and high yielding tolerant varieties. Rapid implementation of this potential will help Saskatchewan maintain its position as the world's leading exporter of large green lentil, and help increase its market share for both whole and split red lentil. The crop industry in Saskatchewan will in future gain substantial economic benefit from the research conducted through this project.

3 Technical Report

3.1 Background

Discovery of the imidazolinone tolerant RH44 lentil line in the late 1990s lead to the development of this research project. In order to exploit the value of this trait in lentil breeding and production in Canada, it was necessary to develop knowledge about the genetics and potential herbicide interactions of the trait.

3.2 Genetic Inheritance Studies

Formal genetic studies of the inheritance of the imidazolinone (IMI) tolerance trait were initiated early in the project so that this knowledge could be applied to the breeding program in a timely and logical manner.

Crosses were made between the IMI tolerant line RH44 and numerous other susceptible lines and parents in the breeding program. Table 1 shows representative data from these types of studies. In all cases we concluded that the IMI tolerance trait was a single dominant gene.

Subsequent use of the trait in breeding confirmed in all cases that the IMI tolerance trait was a single dominant gene, allowing efficient backcrossing and screening methods to be used throughout the project.

Table 1. Genetic Analysis of the Inheritance of the Imidazolinone Tolerant Trait in RH#44 Lentil

Cross No.	Cross code	Pedigree*	Observed Resistant	Observed Susceptible	Total	Expected 3:1 R	Expected 3:1 S	Chi-squred values R	Chi-squred values S	Chi-squred values Sum
1	M19	RH#44 x CDC Milestone	14	6	20	15.0	5.0	0.0667	0.2000	0.2667
2	M17	RH#44 x (1140ZT/CDC Milestone//819-5R)	14	5	20	15.0	5.0	0.0667	0.0000	0.0667
3	M12	RH#44 x (543ZTLB-12/CDC Milestone//CDC Milestone/1132ZT)	12	7	19	14.3	4.8	0.3553	1.0658	1.4211
4	M11	RH#44 x (1060F3/639-27	14	6	20	15.0	5.0	0.0667	0.2000	0.2667
5	M3	RH#44 x (543ZTLB-12/CDC Glamis//CDC Glamis/1132ZT)	16	4	20	15.0	5.0	0.0667	0.2000	0.2667
6	M31	RH#44 x (1049F3/CDC Milestone	17	3	20	15.0	5.0	0.2667	0.8000	1.0667
7	M28R	RH#44 x (CDC Milestone/877-16R)	14	6	20	15.0	5.0	0.0667	0.2000	0.2667
8	M27Y	RH#44//CDC Milestone/819-5R	14	6	20	15.0	5.0	0.0667	0.2000	0.2667
		Total	115	43	159	119.3	39.8	0.1515	0.2657	0.4172
		Chi-square critical value								3.84

CONCLUSION: SINGLE DOMINANT GENE CONFERS RESISTANCE. HOMOGENEOUS REACTION IN ALL POPULATIONS

* Note RH#44 was crossed to a random group of parental lines or F1 plants of heterogeneous genetic origin.

The F1 generation of these hybrid seeds were grown indoors. F2 generation was grown indoors in pots - 20 seeds per cross.

This is the required number of individuals in an F2 genetic study to distinguish single gene reactions from two-gene reactions.

Plants were sprayed with 1X rate of Odyssey at 3 weeks after seeding. Resistant and susceptible ratings were recorded two weeks after Odyssey application.

A more formal genetic study was completed in the summer of 2001 based on two crosses: RH#44 x CDC Milestone and RH#44 x CDC Robin. Reciprocal crosses, test crosses, parents and F_2 populations were sown concurrently, grown for 4 weeks and then exposed to Odyssey at the 1x rate. Results from this study confirmed that the mode of inheritance of the IMI tolerance trait in lentil is a single dominant gene. The results will be published at an appropriate time in 2004.

3.3 Progress in Germplasm Development and Breeding

Backcrosses and three-way crosses were used to introgress the trait into genetic backgrounds in the small red, small green, medium green, and large green market classes. Two to three crossing cycles were completed per year. All breeding nurseries were managed to accommodate the regulations that apply to Plants with Novel Traits in Canada. This added significantly to the cost of genetic improvement efforts by increasing administration and decreasing technical efficiency. For field trials, Odyssey herbicide was applied at 2X rate for screening purposes.

In the second year of the project, a backcrossing strategy was implemented with the goal of developing Odyssey tolerant versions of currently successful commercial varieties in all market classes is well underway. Drought affected this project severely in both 2001 and 2002. Grasshopper damage was also very severe in 2002, particularly at the Elrose location. In the worst cases, damage due to drought and grasshoppers was severe enough that data were deemed unreliable for screening purposes. Table 2 summarizes the scale and scope of the IMI tolerant lentil breeding program. In spite of the limitations imposed

Table 2. Summary of plot numbers and locations for IMI tolerant lentil breeding from 2000-2002.

	2000	2001	2002	2000	2001	2002
	Locations			Number of trials -- plots		
F3 microplot nursery						
Kernen	x	x		1 -- 1500	1 -- 4500	1 -- 500
F4 preliminary yield trial						
Kernen	x			1 -- 170		
Elrose		x	x		10 -- 1620	10 -- 1620
F5 advanced yield trial						
Kernen		x	x		3 -- 216	3 -- 216
Elrose		x	x		3 -- 216	3 -- 216
Vanscoy		x	x		3 -- 216	3 -- 216
F6 elite yield trial						
Kernen			x			1 -- 48
Elrose			x			1 -- 48
Vanscoy			x			1 -- 24

Notes: x = Drought affected sites

2002 F3 nursery consisted of back-cross genotypes only.

by environmental conditions, progress was made and results show in general that the IMI tolerance trait poses no negative influence on yield potential in lentil.

In 2000, about 1500 F3 microplots were sown and sprayed with Odyssey. Surviving lines were harvested at maturity for advancement to 2001 trials. About 85 IMI tolerant F4 lines were available for yield trials in 2000. Table 3 shows the results from the first year of two-replicate preliminary screening trials conducted at Saskatoon. The RH44 line was entered 8 times in Trial 1 to multiply seed and to provide a highly repeated check for both yield and herbicide tolerance. The results clearly indicated that application of Odyssey herbicide reduced yield of the non-tolerant checks in most cases, and that about one third of the F4 lines had higher yield that RH44.

In 2001, testing was conducted on a much larger at three locations. Approximately 110 F_2 populations were sown in 2001, establishing more than 10,000 individual plants. The group of populations represented all major commercial classes of lentil. At the time of harvest in September 2001, selections were made for advancement to the 2002 F3 nursery. At the F3 level, 56 families were grown in microplots, approximately 4500 in total. About 800 were selected and harvested for advancement to single replicate preliminary yield trials in 2002.

Table 4 outlines general results from the Elrose location where the preliminary. Drought was a major factor in increasing the level of variability and decreasing yield in these trials. A summary that indicates the percentage of lines that outyielded RH44 is shown in Table 4. The highest yielding lines were nevertheless selected for 2002 yield trials.

Table 3. Preliminary yield test of IMI tolerant F4 lentil breeding lines in 2000 at Kernen farm

	Test 1 Yield			Test 2 Yield	
Entry	kg/ha	% RH44	Entry	kg/ha	% RH44
Redcap	1501	58	Robin	1214	47
Vantage	608	24	Eston	2802	109
Richlea	912	35	Milestone	2531	98
Eston	1508	58	Richlea	1348	52
Milestone	759	29	M3-3	1767	69
Glamis	1372	53	M3-4	2018	78
Sovereign	1064	41	M11-7	2881	112
Robin	1648	64	M11-9	2233	87
M28-3	3046	118	M11-10	2249	87
(3A)-5	2969	115	M17-6	1689	66
M19-4	2961	115	M17-7	2386	93
(3A)-3	2908	113	M19-7	2146	83
M11-3	2839	110	M27-2	2804	109
(3A)-7	2726	106	M27-4	2612	101
M19-3	2676	104	M27-5	2233	87
M17-1	2660	103	M28-5	2439	95
M19-2	2636	102	M28-6	2162	84
M31-8	2632	102	M28-7	2554	99
M19-1	2620	102	M28-8	2153	84
M19-5	2614	101	M28-9	1534	60
M27-3	2610	101	M28-10	2229	86
M3-1	2607	101	M31-9	2630	102
M17-2	2568	100			
(3A)-9	2524	98			
M11-2	2514	98			
(3A)-8	2504	97			
M31-7	2473	96			
(3A)-1	2471	96			
M31-6	2468	96			
M19-6	2467	96			
M31-10	2437	95			
(3A)-4	2418	94			
(3A)-2	2410	93			
M31-12	2399	93			
(3A)-6	2369	92			
M28-4	2353	91			
M31-5	2341	91			
M31-3	2333	90			
M17-5	2309	90			
M31-4	2295	89			
M31-2	2280	88			
M31-11	2222	86			

M31-1	2128	83
M28-2	2066	80
M28-1	2027	79
M11-1	1966	76
M3-2	1957	76
M17-3	1936	75
M11-4	1920	74
M27-1	1894	73
M11-6	1883	73
M17-4	1720	67
RH44-1	2921	113
RH44-2	2678	104
RH44-3	2476	96
RH44-4	2600	101
RH44-5	2594	101
RH44-6	2296	89
RH44-7	2555	99
RH44-8	2503	97
Mean	2269	88
RH44 mean	2578	100
CV	18.9	

Table 4. Summary of results for 2001 IMI tolerant lentil preliminary yield trials at Elrose.

Trial	CV (%)	Mean yield kg/ha	% of lines exceeding mean of checks
1	32.0	414	50
2	27.7	452	68
3	37.8	381	38
4	30.8	385	44
5	37.5	356	29
6	38.1	392	45
7	30.6	553	76
8	37.2	455	63
9	36.2	573	81
10	54.4	430	56
Mean	36.2	439	55

In 2001, advanced yield trials were grown at Elrose, Saskatoon (Kernen Farm) and Vanscoy. The Elrose data were not meaningful due to extremely lows yield induced by drought. Table 5 shows that that many IMI tolerant breeding lines had higher yield potential than RH44, and that IMI susceptible checks had substantial yield reduction when sprayed with the 2X rate of Odyssey herbicide.

Table 5. Yield of advanced IMI tolerant lentil yield trials of lentil in 2001at three locations

	Yield of Advanced Test 1 when sprayed with 2x rate of Odyssey					Yield of Advanced Test 1 with no Odyssey				Kernen and Vanscoy
	Elrose	Kernen	Vanscoy	Mean	%	Kernen	Vanscoy	Mean	%	unsprayed as
Name			kg/ha		RH44		kg/ha		RH44	% of sprayed
RH-44	563	342	2735	1213	100	440	1254	847	100	55
Robin	478	137	1381	665	55	306	1254	780	92	103
CDC Milestone	710	67	1445	741	61	349	1578	964	114	127
CDC Blaze	473	166	1243	627	52	298	632	465	55	66
CDC Vantage	591	40	459	364	30	561	1095	828	98	332
Richlea	438	20	381	280	23	628	984	806	95	402
CDC Plato	398	44	329	257	21	820	1158	989	117	530
950-8	456	157	1019	544	45	664	1633	1149	136	195
(3A)-9	700	298	1920	973	80	372	1063	717	85	65
M11-2	445	420	2089	984	81	358	1375	867	102	69
(3A)-8	496	327	2686	1170	96	268	1238	753	89	50
M31-7	634	356	2461	1150	95	449	1655	1052	124	75
(3A)-1	577	392	2564	1177	97	449	1670	1060	125	72
M28-3	547	445	2818	1270	105	347	884	615	73	38
(3A)-5	524	381	3015	1307	108	668	1552	1110	131	65
M19-4	504	400	2857	1254	103	456	1626	1041	123	64
(3A)-3	520	390	2970	1293	107	326	1895	1110	131	66
M11-3	576	466	2856	1299	107	566	1467	1016	120	61
(3A)-7	660	416	2727	1267	104	435	1614	1024	121	65
M19-3	357	325	2718	1133	93	426	1248	837	99	55
M17-1	529	334	2660	1174	97	338	1561	950	112	63
M19-2	432	389	2186	1002	83	403	1407	905	107	70
M31-8	458	311	2929	1233	102	529	1076	802	95	50
M19-1	437	304	2399	1046	86	618	1193	906	107	67
M19-5	464	272	2923	1220	101	354	1080	717	85	45
M27-3	620	404	2371	1132	93	293	1220	757	89	55
M3-1	345	479	2421	1082	89	543	1708	1126	133	78
M17-2	338	346	2527	1070	88	476	999	738	87	51
M11-7	550	314	2778	1214	100	512	1208	860	102	56
M11-10	642	409	2659	1236	102	610	1323	967	114	63
M17-7	524	486	2560	1190	98	445	1510	977	115	64
M27-2	539	467	2684	1230	101	473	1343	908	107	58
M27-4	216	416	2136	923	76	249	1475	862	102	68
M28-5	549	468	2494	1170	96	637	1646	1142	135	77
M28-7	356	366	2406	1043	86	418	794	606	72	44
M31-9	484	353	2373	1070	88	457	1580	1019	120	75
Mean	504	325	2255			459	1333			
CV %	**25.4**	**37.6**	**18.1**			**24.5**	**26.3**			
Reps	2	2	2			2	2			

Note: Entries in **BOLD** are not tolerant to Odyssey

Nurseries were established at 3 locations in 2002. Drought conditions were more severe than in 2001, and grasshoppers caused damage beginning in August. The F3 microplot nursery in Saskatoon was harvested in late October. Most plots produced sufficient seed for continuation of yield trial sin 2003. All preliminary and advanced yield trials at Elrose produced no meaningful data because of drought and grasshoppers.

The advanced and elite level trials at the Kernen Farm in Saskatoon produced satisfactory results in 2002 (Tables 6 and 7). All trials were sprayed with the 2X rate of Odyssey. Results clearly showed once again that non-tolerant lines had severely reduced yield, and that many breeding lines had much higher yield potential compared to RH44. This may indicate that many of the breeding lines have resistance to ascochyta blight whereas RH44 is susceptible. The nursery was seeded in late May and responded well to rainfall on June 10. Abnormally high levels of rainfall in August may have contributed to development of late season foliar diseases such as ascochyta and possibly botrytis gray mold.

Table 6. Yield of 3 advanced IMI tolerant lentil trials in 2002 at the Kernen farm in Saskatoon

2002 Advanced Trial 1 Kernen			2002 Advanced Trial 2 Kernen			2002 Advanced Trial 3 Kernen		
	Yield			Yield			Yield	
Entry	kg/ha	% RH44	Entry	kg/ha	% RH44	Entry	kg/ha	% RH44
CDC Milestone	165	19	CDC Milestone	305	20	CDC Milestone	166	10
RH-44	874	100	RH-44	1514	100	RH-44	1596	100
CDC Vantage	161	18	CDC Vantage	0	0	CDC Vantage	149	9
CDC Robin	727	83	CDC Robin	197	13	CDC Robin	754	47
M12-10-18	1635	187	M52-7	1891	125	M40-2-1	929	58
M12-10-27	2366	271	M53-13	1774	117	M43-7	1705	107
M31Y-2-10	1940	222	M53-21	1368	90	M43-12	1032	65
M31Y-2-11	2175	249	M54-21	1184	78	M11-11	1186	74
M31Y-2-17	1742	199	M54-22	1683	111	M11-22	1513	95
M31Y-2-3	1449	166	M54-29	1976	131	M11-29	1809	113
M31Y-3-11	1726	198	M54-38	1833	121	M12-6-1	1229	77
M31Y-3-12	988	113	M54-44	1898	125	M33-16	2281	143
M31Y-3-26	1264	145	M54-5	1221	81	M33-23	1930	121
M31Y-3-31	1721	197	M54-56	1748	115	M34-11	1796	112
M31Y-3-32	1729	198	M54-59	1465	97	M34-12	1858	116
M31Y-3-34	2630	301	M54-8	817	54	M34-14	1931	121
M31Y-3-46	1611	184	M57-10	243	16	M34-16	2274	142
M31Y-3-6	1660	190	M57-12	1913	126	M34-23	1840	115
M38-1-5	2450	280	M57-17	1746	115	M34-5	1507	94
M38-1-6	1434	164	M57-18	1609	106	M36-16	2242	140
M38-1-8	1176	135	M57-2	1788	118	M36-2	1612	101
M41-14	1897	217	M57-21	1758	116	M36-6	1142	72
M41-15	2495	285	M57-7	1770	117	M37-1-1	2227	139
M41-2	2054	235	M59-24	1614	107	M37-1-21	1501	94
M41-9	2030	232	M59-34	1104	73	M37-1-5	1757	110
M42-18	1978	226	M59-4	1364	90	M37-2-10	2049	128
M42-22	1860	213	M11-16	1259	83	M37-2-4	1396	87
M43-30	2407	275	M36-19	1376	91	M37-2-8	1865	117
M44-11	1089	125	M37-1-11	1804	119	M43-16	2368	148
M44-4	2025	232	M37-1-3	1176	78	M43-17	1763	110
M52-11	1875	215	M37-2-15	1592	105	M43-18	2327	146
M52-20	1477	169	M37-2-2	1045	69	M43-4	1576	99
M52-30	1947	223	M37-2-9	1381	91	M43-9	1869	117
M52-49	2564	293	M40-1-13	1602	106	M27-7	1537	96
M52-52	2428	278	M40-1-2	1100	73	M59-60	2001	125
M52-64	1687	193	M40-1-5	1041	69	M40-2-12	1859	116
Mean	1707		Mean	1357	90	Mean	1627	
CV	17		CV	17		CV	13	
LSD (0.05)	533		LSD (0.05)	437		LSD (0.05)	408	

Table 7. Results of elite yield trial of IMI tolerant lentil grown at Saskatoon in 2002					
	Yield				Yield of
	Unsprayed		Sprayed with 2X Odyssey		unsprayed
Entry	kg/ha	% RH44	kg/ha	% RH44	as % of sprayed
Milestone	1055	74	106	6	999
RH-44	1434	100	1754	93	82
M31-7	2223	155	1709	91	130
(3A)-1	1152	80	2110	112	55
(3A)-5	1804	126	1833	97	98
M19-4	2412	168	1593	85	151
M11-3	1521	106	1782	95	85
M11-10	1714	120	1410	75	122
M17-7	2011	140	1674	89	120
M27-2	1703	119	1107	59	154
M28-5	1558	109	1555	83	100
M31-9	2460	172	1932	103	127
Mean	1754		1547		
CV	**13**		**17.0**		
LSD	408		473		
Note: Milestone is not tolerant to Odyssey					

3.4 Agronomic Studies Involving IMI Tolerant Lentils

3.4.1 Background

A series of agronomic experiments were performed to provide baseline information for herbicide registration for IMI tolerant lentil varieties. Much of this work was conducted as part of an M.Sc. thesis project for Shannon Chant. These experiments involved standard herbicide applications under greenhouse conditions or under field conditions in 2001.

All protocols used were standard comparisons of herbicide application rates, cross resistance, or timing applications applied to the IMI tolerant lentil line RH44. Comparisons were made to unsprayed controls, to metribuzin or to IMI susceptible cultivars. In most cases, the imidazolinone herbicide used was imazamox which is one of the active ingredients in Odyssey. This report summarizes the main results of various studies. An M.Sc. thesis that will formally present all details is in preparation.

3.4.2 Effect of Rate of Odyssey Application on RH44 Lentil

Under greenhouse conditions, imazamox application caused no significant decrease in height of RH44 compared to the control after 2 weeks over a range of application rates

from 1x to 8x (Table 8). The 8x rate caused a significant delay in flowering. In general, imazamox applications in this experiment under greenhouse conditions showed minimal effects on changes in dry weight or yield. Metribuzin application at the 1x rate resulted in a significant decrease in dry weight at maturity, but no significant decrease in seed yield. In general, all rates of imazamox had minor effects on RH44.

Table 8. Effect of rate of application of imazamox on agronomic characters of RH44 lentil grown under greenhouse conditions

Herbicide Applied	Rate of herbicide applied	Height before application	Height 1 week after application	Height 2 weeks after application	Height at maturity	Days to first flower	Dry weight at maturity	Seed yield
		(cm)	(cm)	(cm)	(cm)		(g)	(g)
Untreated	0	18.9 a	26.9 a	32.9 a	46.6 ab	42 c	2.7 a	0.6 ab
Metribuzin	1x	18.6 a	22.2 bc	24.8 a	42.8 b	44 b	1.9 b	0.3 b
Imazamox	1x	18.0 a	25.9 a	31.7 a	49.6 ab	42 c	2.9 a	0.5 b
Imazamox	2x	17.8 a	24.3 ab	28.7 a	48.3 ab	43 bc	3.0 a	0.9 a
Imazamox	4x	18.2 a	23.1 bc	28.8 a	58.4 a	43 bc	2.5 ab	0.4 b
Imazamox	8x	17.8 a	21.1 c	33.1 a	51.0 ab	50 a	2.4 ab	0.3 b
LSD (0.05)		1.6	3.0	12.4	13.0	2	0.8	0.4

Values are expressed on a per plant basis unless otherwise indicated.
Means with the same letter are not significantly different.

The corresponding field experiment was grown at the Kernen Farm in 2001, a season characterized by drought, generally resulting in reduced plant growth and low weed populations. Under field conditions, the effects of all herbicides and rates on plant height were similar to greenhouse conditions in that slight reductions in plant height occurred at two weeks after application (Table 9). Height differences were not evident at maturity. Herbicide effects on dates to first flower were less than those observed in the greenhouse, with no treatments significantly different than the control. Dry weight estimations based on 10-plant samples were variable, probably obscuring treatment effects. The seed yield of RH44 for all imazamox treatments was higher but not significantly different compared to the control. The 1x, 2x and 3x imazamox treatments did, however, result in significantly higher yield of RH44 lentil compared to the 1x metribuzin treatment.

Table 9. Effect of rate of application of Odyssey on agronomic characters of RH44 lentil grown under field conditions in 2001

Herbicide Applied	Rate of herbicide applied	Height (cm)			Days to 1st flower	Dry weight (g)	Yield per plot (kg/ha)
		Before application	2 weeks after application	Maturity			
Untreated	0	8	14	23	52	27	417
Metribuzin	1x	8	16	23	51	20	348
Imazamox	1x	8	14	23	50	28	471
Imazamox	2x	9	14	22	50	22	464
Imazamox	4x	8	14	23	51	31	463
Imazamox	8x	9	13	22	53	30	419
LSD(0.05)		1	2	1	2	8	112

3.4.3 Effect of Timing of Herbicide Application on RH44

A greenhouse study in pots comparing the effect of imazamox and metribuzin at the 1x rate on RH44 lentil at 5 different growth stages showed that plant height for all herbicide treatments was greater than the control at all growth stages except the 11 node stage (close to flowering). Plants treated with herbicide flowered slightly earlier than the unsprayed control. When dry weight at maturity was considered, all imazamox treatments, regardless of growth stage of application, produced more dry matter than the metribuzin treatments.

Table 10. Effect of growth stage of application of imazamox and metribuzin on agronomic characteristics of RH44 lentils when grown under greenhouse conditons

Node stage at herbicide application	Herbicide applied	Plant height (cm) after application				Days to first flower	Dry weight at maturity (g)
		0 week	1 week	2 weeks	Maturity		
3	Imazamox	9	17	26	48	44	2.8
3	Sencor	9	13	22	52	47	2.1
3	Control	10	17	25	41	nd	nd
5	Imazamox	13	19	26	44	46	2.8
5	Sencor	13	19	27	47	45	2.3
5	Control	12	20	27	41	nd	nd
7	Imazamox	19	28	36	50	44	2.9
7	Sencor	19	24	28	46	46	1.9
7	Control	18	25	32	41	nd	nd
9	Imazamox	26	36	44	Nd	44	2.7
9	Sencor	25	27	30	44	46	1.6
9	Control	23	30	37	41	nd	nd
11	Imazamox	34	41	45	44	47	3.0
11	Sencor	36	40	40	37	47	1.2
11	Control	30	37	42	41	nd	nd
untreated	Control					48	2.6
LSD(0.05)		2	3				

Means are based on samples of 5 plants, 4 replicates.

nd - no data

The field study of timing of application included both the IMI tolerant RH44 and the susceptible cultivar CDC Milestone. Differences in plant height were most obvious at 2 weeks after herbicide application. Imazamox application caused a significant reduction in plant height compared to metribuzin application at all growth stages for CDC Milestone. Height differences were much smaller between imazamox and metribuzin treatments for RH44. The drought conditions of 2001 may have affected the flowering response of CDC Milestone because under normal conditions it would be expected to flower before RH44.

Table 11. Effect of time of application imazamox and metribuzin on agronomic characteristics of RH44 and Milestone lentil grown under field conditions at Saskatoon, 2001.

Node stage at herbicide application	Herbicide applied	Cultivar	Plant height before application (cm)	Plant height 1 week after application (cm)	Plant height 2 weeks after application (cm)	Plant height at maturity (cm)	Days to first flower	Dry weight at maturity (g)	Yield per plot (kg/ha)
5	Imazamox	RH44	4.8	7.8	10.7	24.2	56	30.9	902
5	Imazamox	Milestone	4.8	5.3	5.1	23.3	54	32.3	743
5	Metribuzin	RH44	4.9	8.3	11.1	23.7	50	24.7	853
5	Metribuzin	Milestone	5.1	7.3	9.8	23.2	57	41.1	772
7	Imazamox	RH44	9.1	9.0	13.8	23.7	52	34.1	883
7	Imazamox	Milestone	8.2	7.1	7.2	26.3	52	36.5	651
7	Metribuzin	RH44	8.4	8.9	15.3	24.2	53	32.3	685
7	Metribuzin	Milestone	8.5	8.1	14.0	22.6	55	32.3	592
9	Imazamox	RH44	10.6	16.7	20.6	24.5	54	37.8	807
9	Imazamox	Milestone	10.5	10.8	10.9	26.4	51	36.2	193
9	Metribuzin	RH44	11.8	15.2	19.5	23.1	51	25.9	769
9	Metribuzin	Milestone	10.4	14.8	19.9	22.1	55	29.7	611
11	Imazamox	RH44	16.2	21.2	23.9	23.9	57	32.3	753
11	Imazamox	Milestone	16.5	17.6	18.7	24.7	52	29.6	7
11	Metribuzin	RH44	15.7	19.9	22.9	22.8	52	26.6	518
11	Metribuzin	Milestone	14.9	19.1	20.5	21.3	55	29.0	386
13	Imazamox	RH44	20.8	24.6	23.6	23.7	52	31.7	752
13	Imazamox	Milestone	20.4	20.9	20.6	24.9	54	37.6	2
13	Metribuzin	RH44	25.4	25.4	24.5	25.3	57	33.2	776
13	Metribuzin	Milestone	24.3	24.3	23.0	23.5	51	34.4	712
Untreated Check		RH44					52	30.0	737
Untreated Check		Milestone					57	31.0	750
LSD(0.05)			1.5	1.9	1.9	1.5	8	12	129

Table 12. Effect of imazamox and metribuzin at 1x and 2x application rates on plant height, days to first flower, dry weight at maturity and seed yield for 6 lentil cultivars grown at Saskatoon, 2001

12 A Plant height (cm) 2 weeks after herbicide application

Cultivar[a]	Herbicide and rate applied[b]				
	0x- Untreated	1x-Imazamox	2x-Imazamox	1x-Metribuzin	2x-Metribuzin
RH44	12.2	12.8	12.1	12.3	12.0
CDC Richlea	12.5	6.2	6.7	12.8	12.5
CDC Glamis	11.7	6.3	6.6	12.4	12.9
CDC Vantage	13.2	7.5	6.6	13.7	13.3
CDC Milestone	10.9	5.4	5.3	12.0	11.6
CDC Robin	10.5	5.1	4.8	10.2	8.2

[a] LSD(0.05) for comparisons within colums = 0.6

[b] LSD(0.05) for comparisons within rows = 0.6

12 B Plant height at maturity

Cultivar[a]	Herbicide and rate applied[b]				
	0x-Untreated	1x-Imazamox	2x-Imazamox	1x-Metribuzin	2x-Metribuzin
RH44	24.4	24.3	24.6	24.4	25.3
CDC Richlea	27.5	30.7	30.8	26.8	27.7
CDC Glamis	33.4	35.1	35.4	34.0	33.9
CDC Vantage	28.3	30.8	31.4	28.1	28.1
CDC Milestone	22.8	25.8	25.5	23.5	23.5
CDC Robin	24.9	22.8	26.7	23.5	23.5

[a] LSD(0.05) for comparisons within colums = 0.9

[b] LSD(0.05) for comparisons within rows = 0.8

12 C Days to first flower

Cultivar[a]	Herbicide and rate applied[b]				
	0x- Untreated	1x-Imazamox	2x-Imazamox	1x-Metribuzin	2x-Metribuzin
RH44	55	57	55	55	57
CDC Richlea	57	61	62	57	57
CDC Glamis	57	58	61	57	57
CDC Vantage	57	60	62	57	57
CDC Milestone	58	57	61	57	57
CDC Robin	55	57	57	53	53

[a] LSD(0.05) for comparisons within columns = 2

[b] LSD(0.05) for comparisons within rows = 1

12 D Dry weight (g) at maturity based on 10 plant sample

Cultivar[a]	Herbicide and rate applied[b]				
	0x- Untreated	1x-Imazamox	2x-Imazamox	1x-Metribuzin	2x-Metribuzin
RH44	17.2	21.3	23.0	15.2	19.6
CDC Richlea	20.0	28.8	24.6	20.1	21.6
CDC Glamis	25.5	28.2	24.5	21.0	25.8
CDC Vantage	23.5	31.2	24.5	23.1	24.3
CDC Milestone	16.7	28.8	24.6	15.8	14.8
CDC Robin	18.8	20.1	32.8	14.7	13.2

[b] LSD(0.05)

3.4.4 Tolerance of Current Lentil Varieties to 1X and 2X Rates of Imazamox and Metribuzin

Results from a field experiment compared reaction of RH44 and 5 current lentil cultivars to 1x and 2x rates of imazamox and metribuzin clearly showed that IMI susceptible lines had significantly reduced plant height two weeks after application compared to controls (Table 12 A) Height differences were not obvious at plant maturity (Table 12B) Imazamox at both rates significantly increased the number of days to first flower for all susceptible cultivars by almost a week, but the IMI tolerant line RH44 had no change in flowering date (Table 12 C). Metribuzin had minimal effect on flowering delay.

Patterns of herbicide influence on dry matter accumulation and final yield were variety specific and were highly influenced by the late season rainfall event that occurred in late July/early August. RH44 was relatively unaffected by either herbicide or rate of application. Medium and late maturing IMI susceptible cultivars like Richlea, CDC Vantage and CDC Glamis had significantly reduced yield at either the 1x or 2x rate of imazamox compared to either the control or the metribuzin treatments (Table 12 D and 12 E). In contrast, the relatively early maturing cultivars like CDC Milestone and CDC Robin had a completely different response. The drought conditions reduced yield potential relative to the other cultivars for control treatments. The imazamox treatment significantly increased yield of CDC Milestone and CDC Robin at either the 1x or 2x rate, but metribuzin had no effect. This response is explained by the delay in flowering of the imazamox treatments which allowed the flowering and pod-filling stages for these two cultivars to be delayed until the period when soil moisture was replenished by the single late July rainfall event.

3.4.5 Cross Resistance of RH44 Lentil to Other Group 2 Herbicides

Effects of other Group 2 herbicides were tested on both the IMI tolerant line RH44 and the IMI susceptible control CDC Milestone. The study was conducted under both greenhouse and field conditions. Data presented in Table 13 summarize the greenhouse response. Field results were similar but were affected more by drought and hail at harvest, so results were more variable. Neither line was tolerant of Refine, Express or Everest as measured by dry weight at maturity or seed yield. Some growth recovery was evident for Refine and Express, but the level was uneconomic. Pursuit (imazethapyr) application was tolerated by both RH44 and CDC Milestone based on dry weight, seed yield and number of pods produced. The Odyssey (imazamox/imazethapyr mixture) and AC 299,263 (imazamox) treatments had no effect odry weight or seed yield of RH44 but caused significant reduction in seed yield and number of pods for CDC Milestone.

Table 13. Effect of herbicide application on dry weight, seed yield and pod number of RH44 and CDC Milestone grown under greenhouse conditions.

Herbicide applied	Dry weight at maturity (g)		Seed yield (g)		Number of pods	
	Cultivar		Cultivar		Cultivar	
	RH44	CDC-M	RH44	CDC-M	RH44	CDC-M
Untreated	42.6	36.2	9.5	12.2	25	44
Odyssey	nd	44.7	14.4	5.7	39	23
Pursuit	43.2	48.5	10.3	12.2	39	36
AC 299,263	41.3	46.1	14.3	2.3	39	14
Refine	43.2	17.8	3.3	2.9	19	27
Express	34.6	21.2	8.7	7.8	28	30
Everest	4.0	2.5	0.0	0.0	n/a	n/a
LSD (0.05) Herbicides	8.6	8.6	2.2	2.2	9	9
LSD (0.05) Cultivars	4.1		3.9		5	

Notes: Values are expressed on the basis of a sample of 10 plants.
RH44 is tolerant to imidazolinones; CDC-M (Milestone) is susceptible.

3.5 Conclusions

The results of this research show that:

1. Imidazolinone tolerance, as shown by high levels of tolerance to imazamox and imazethapyr is conferred by a single dominant gene in RH44 lentil.

2. Plant breeding using RH44 lentil as donor of IMI tolerance, particularly in backcross applications, can be used to develop new lentil cultivars with tolerance to imidazolinone herbicide formulations. This should allow for increased yields due to improved control of broadleaved weeds.

3. RH44 lentil can tolerate imazamox application up to 8x of the normal rate used for pea production.

4. The 1x and 2x rates of imazamox applied to RH44 lentil cause no delay in flowering or reduction in yield potential.

5. RH44 lentil can tolerate imazamox application anywhere from the 3 node to the 11 node stage.

6. RH44 lentil does not tolerate application of the group II herbicides Refine, Express or Everest.

7. All current lentil cultivars in Saskatchewan are likely susceptible to delay in flowering and potential yield loss due to susceptibility to the imidazolinone herbicides imazethapyr and imazamox

3.5 Information of Interest to Producers, Industry and Government

- It is possible to develop a research strategy for rapid development of imidazolinone tolerance in Saskatchewan lentil varieties.

- This project was conducted under regulations in Canada that pertain to Plants with Novel Traits. Information gathered during this project should be kept confidential until such time that unrestricted clearance is granted for this trait in lentil. Premature release of information could jeopardize the commercialization potential of this research.

- At some future time when unrestricted PNT clearance may be granted, this potential new technology could be demonstrated at Agri-Arm sites across Saskatchewan. Some consideration could be given to agronomic research that would investigate how lentil cultivars with IMI tolerance could be best used in Saskatchewan cropping systems.

4. Personnel

Shannon Chant, an MSc candidate in the department of Plant Sciences and Naga DeSilva, a, Technician in the Crop Development Centre was paid form this account. A summer student, Elizabeth Stewart, was paid from this account from May/01 to August/01.

5. Equipment

No equipment with a value of >$500 has been purchased.

6. Project Developed Materials

None.

7. Project Photos

None.

8. Acknowledgement

This work has not been made a feature at field days or extension meetings. We want to keep the project results at a low profile until we are certain we have a commercially useful product that will not jeopardize any of our lentil markets. Thus, there has not been an opportunity to publicly acknowledge the department's support.